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In-Space Propulsion Technology
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National Aeronautics and Space Administration

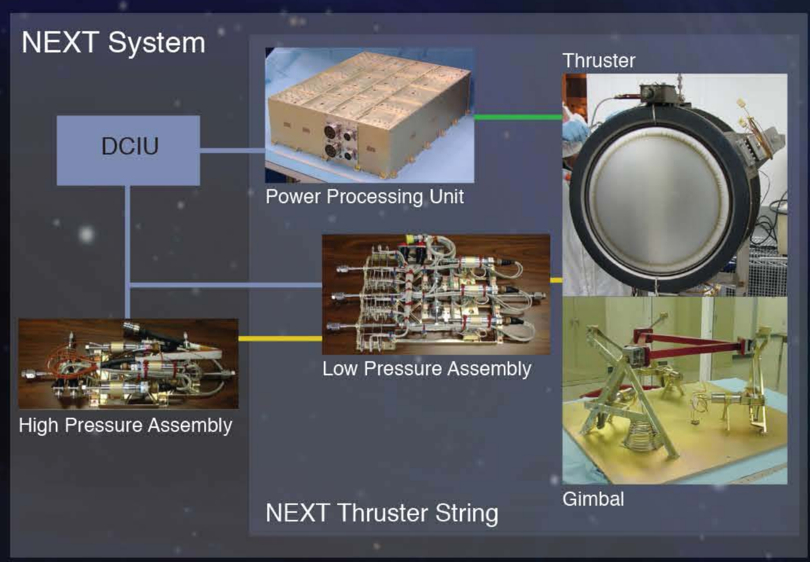
Products from NASA's In-Space Propulsion Program Applicable to Low-Cost Planetary Missions

In-Space Propulsion Technology Overview

The In-Space Propulsion Technology (ISPT) Program, funded by NASA's Science Mission Directorate (SMD), is continuing to invest in propulsion technologies that will enable or enhance NASA robotic science missions by increasing performance while reducing mission cost, risk, and trip times. The primary investments and products intended for technology infusion include NASA's Evolutionary Xenon Thruster (NEXT), the Advanced Materials Bipropellant Rocket (AMBR) engine, the High Voltage Hall Accelerator (HiVHAC) propulsion system, propulsion components (propellant tanks, and flow control systems), Entry Vehicle Technologies (EVT) and Aerocapture. In addition mission and trajectory design tools are being developed and validated to quantify mission benefits of incorporating these new technologies.

NASA's Evolutionary Xenon Thruster (NEXT)

The NASA's Evolutionary Xenon Thruster (NEXT) ion propulsion system has been developed under the NASA ISPT project. NEXT has been analyzed for a wide range of NASA robotic science missions, including near-term New Frontiers and Discovery class mission opportunities. Several missions are enhanced or enabled by NEXT over state-of-art electric propulsion and chemical alternatives. High fidelity NEXT hardware has been produced by the government/industry team, including a flight prototype model (PM) thruster, an engineering model (EM) power processing unit, EM propellant management assemblies, a breadboard gimbal, and control unit simulators. Sub-system and system level technology validation testing is in progress. To achieve the objective Technology Readiness Level 6, environmental testing is being conducted to qualification levels in ground facilities simulating the space environment. Additional tests have been conducted to characterize the performance range and life capability of the NEXT thruster. The status and results of technology validation testing accomplished to date are summarized.



NEXT System Components

Subsystem Characteristics

- Thruster
  - 0.55-6.9 kW input power
  - 25-237 mN thrust range
  - 4,190 s Isp at full power
  - > 70% efficient at full power
  - > 32 × 10^6 N-s total impulse
- Power Processing Unit
  - 89-95% efficient over throttle range
- NEXT Element Masses
  - Thruster: 12.8 kg
  - PPU: 34.5 kg
  - HPA: 1.9 kg
  - LPA: 3.1 kg
  - Gimbal: 6.0 kg

Prototype Model (PM) Thruster

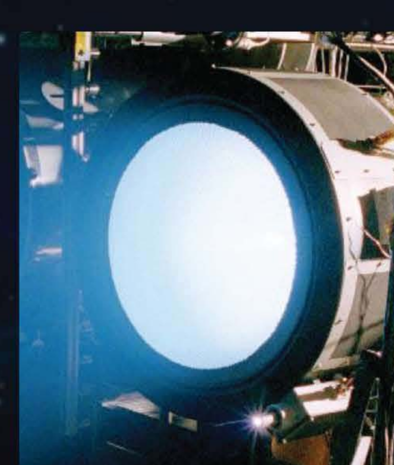
✓Performance Acceptance Testing – Complete
✓Qual-Level Environmental Test – Complete

Engineering Model (EM) PPU

✓Performance Acceptance Testing – Complete
✓Plans for Qual Model PPU, enviromental & integration tests under development

EM Propellant Management System

Flight-like Low Pressure and High Pressure Assemblies have completed full subsystem validation testing.
✓Performance Acceptance Testing – Complete
✓Qual-Level Environmental Test – Complete

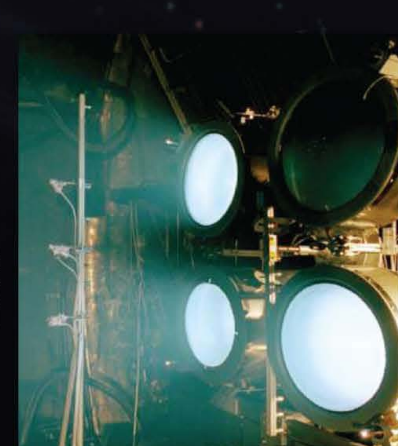

NEXT Thruster Test

System Validation

✓Multi-thruster system testing and modeling – Complete
✓Single-string system integration test – Complete

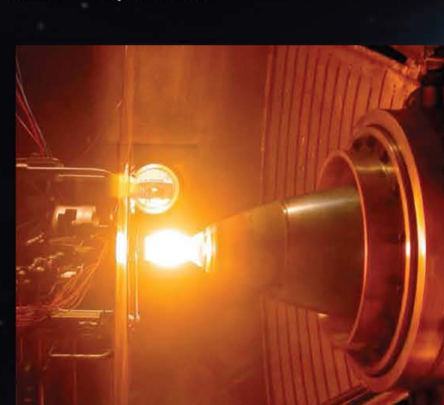
Thruster Life Validation

Validation of the NEXT thruster life requirement is being addressed through a combination of test and analyses to meet the mission based requirement of: 300 kg xenon throughput, 450 kg qualification-level demonstration
✓850 kg xenon throughput with over 47,000 hrs of operation (4/13)
✓32.7 × 106 N-sec total impulse, highest ever achieved on an ion thruster
✓Demonstrated thruster throughput qualification level: >566 kg (exceeded goal)
✓Long duration test being voluntarily terminated for extensive post-test inspections


NEXT Thruster Interaction Test

Advanced Material Bipropellant Rocket (AMBR) Engine

The Advanced Material Bipropellant Rocket (AMBR) engine has been developed with Aerojet to increase the performance of an Earth-storable NTO/N_2H_4 100 lb_f engine. The specific impulse was increased from 328s of specific impulse to 333s, while lowering the cost of the thruster chamber by 30%. The AMBR engine leverages the state-of-the-art HiPAT™ engine, but uses a new El-form™ process to fabricate an iridium / rhenium chamber and engine design modifications to achieve higher operating temperatures.


AMBR Performance Test

Lightweight Composite Overwrap Tanks

The ISPT project is currently planning to design and develop positive expulsive ultra light-weight tanks specifically for the MSL SkyCrane. These tanks can offer mass savings on the order of 24kg, which is a 48% reduction relative to SOA titanium tanks, and therefore increase the landed mass capability of SkyCrane for a relatively low cost per kg. While the tank design is intended for a future SkyCrane application, the technology will be broadly applicable for a wide range of future science missions.


5 -mil Aluminum liner, PBO composite

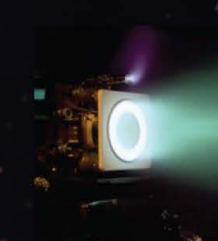
Low Cost Hall Propulsion System

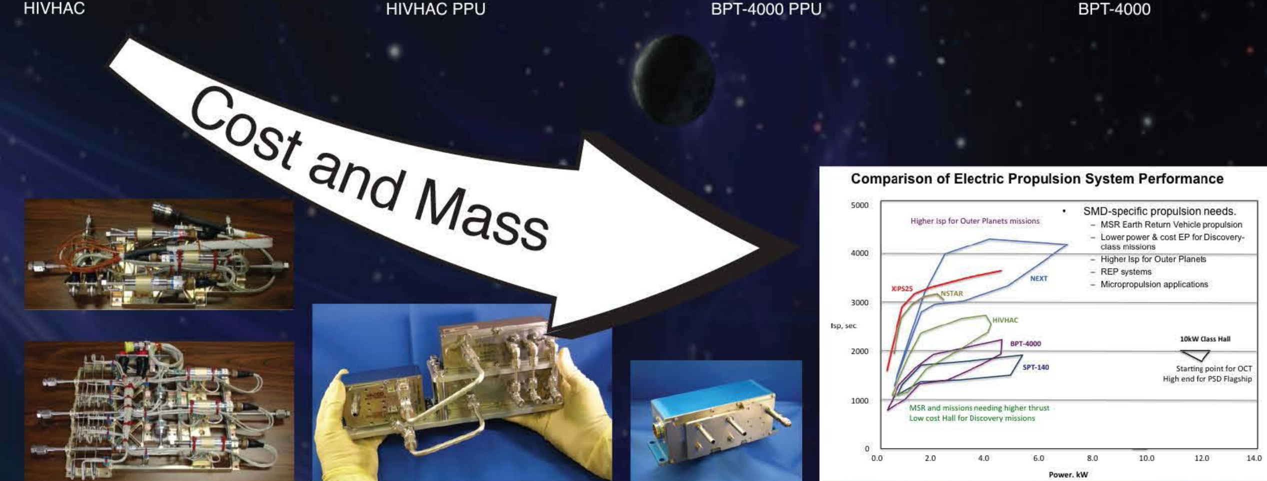
ISPT is investing in a low-cost, high-voltage, Hall Propulsion System option for planetary science missions. The critical components of a Hall Propulsion System include a thruster, power processing unit and xenon feed system. By increasing the operating voltage of conventional Hall thrusters, the specific impulse of these devices can be increased from 2,000 seconds to 2,700 seconds, which improves thruster system capability and increases science return. Several thruster options are under evaluation, which includes variations of a BPT-4000 thruster and HIVHAC thruster. By increasing the input voltage range capability of the PPU, these devises can be made to operate beyond 1-AU Earth orbits to more demanding environments of planetary missions. There are several power processor unit (PPU) options under evaluation, which include a BPT-4000 PPU and a HIVHAC PPU. Although there are many xenon feed system options, ISPT has invested in a low-cost, compact xenon flow control module that can operate either a BPT-4000 or HIVHAC thruster.


HIVHAC


HIVHAC PPU


BPT-4000 PPU

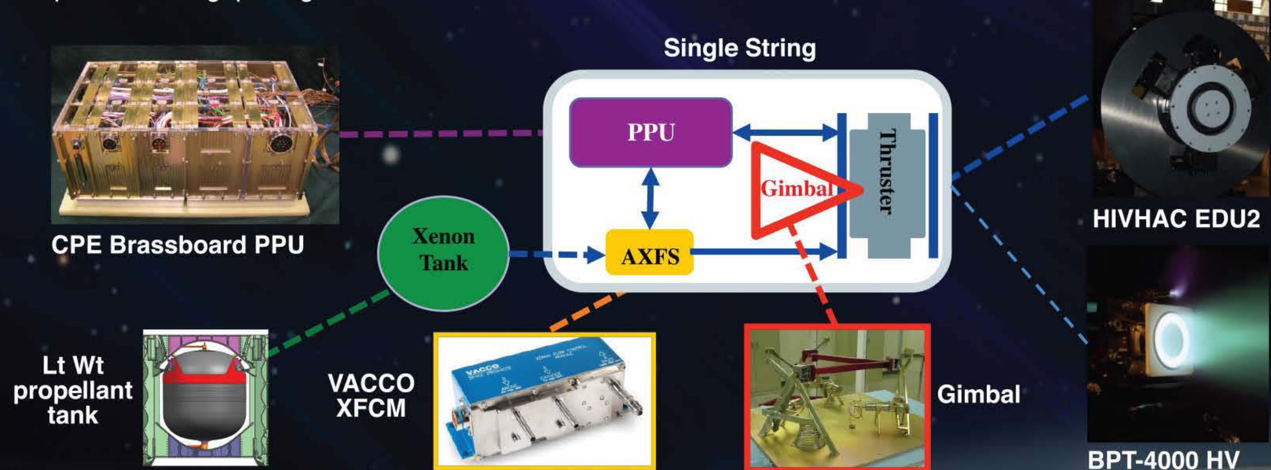

BPT-4000



Advanced Xenon Flow System

Performance Characteristics of HIVHAC vs. SOA Hall (BPT-4000)

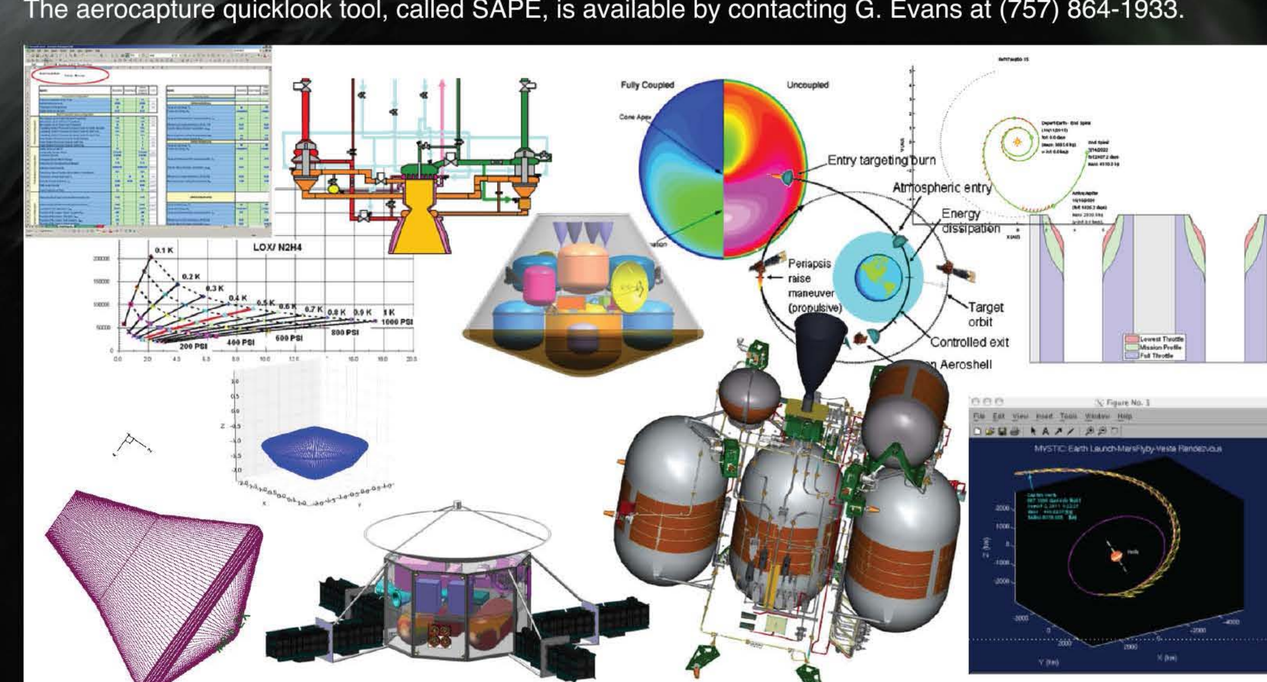
Characteristic	BPT-4000	HIVHAC
Thruster Power Range, kW	0.3-4.5	0.3-3.9
Throttle Ratio	15:1	12:1
Operating Voltage, V	150-400	200-700
Specific Impulse, sec	710-2100	860-2700
Thrust, mN	22-260	20-207
Efficiency	0.25-0.58	0.32-0.62
Propellant Throughput, kg	450	>300



Systems Analysis and Tools

Systems analysis efforts are a key part of any technology program. Systems analysis is used to determine requirements for technology development and to quantify the potential return on investment. In addition to guiding investments, systems analysis also develops the tools necessary to properly evaluate the total mission impact or benefit of new propulsion technologies. The ISPT project has created several tools including the Advanced Chemical Propulsion System (ACPS) sizing tool, the low-thrust trajectory suite including Mystic, currently in use on the Dawn mission, OTIS, used for launch vehicle design, Copernicus, the baseline trajectory tool for human exploration, and MALTO a low-thrust optimization program for preliminary mission design and evaluation. ISPT has also developed an aerocapture quicklook tool to allow potential missions users to rapidly design an aerocapture or entry system and assess the mission level benefits. Information on obtaining the low-thrust trajectory tools can be found on the ISPT website http://spaceflightsystems.grc.nasa.gov/Advanced/ScienceProject/ISPT/LTTT/.

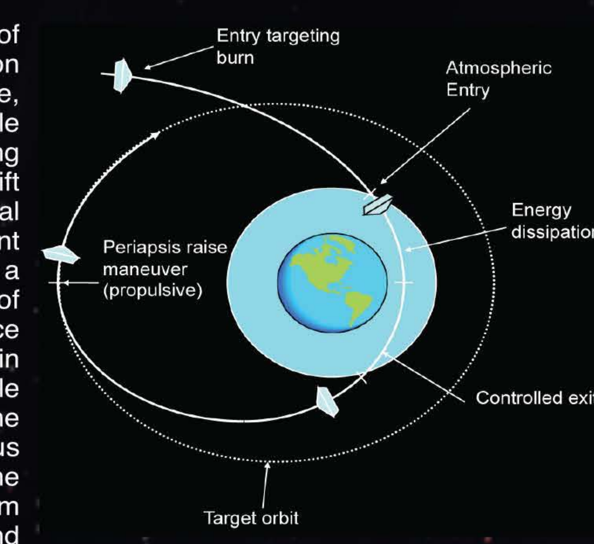
The aerocapture quicklook tool, called SAPE, is available by contacting G. Evans at (757) 864-1933.



Collage of Systems Analysis and Tools available

Aerocapture

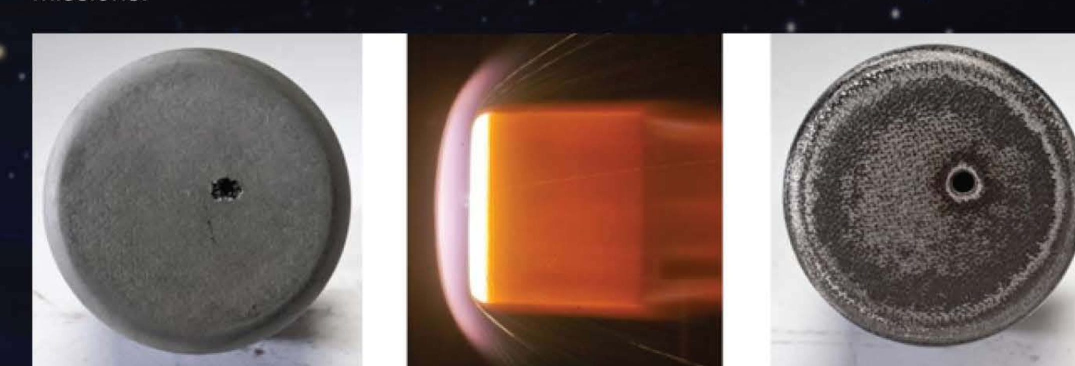
Aerocapture is a mass-efficient method of establishing a science orbit about a planet or moon with an atmosphere. The approaching vehicle, enclosed in a protective aeroshell, makes a single pass through the atmosphere at the destination using atmospheric drag to slow down and aerodynamic lift to steer to the proper target altitude. Using the natural resource of the atmosphere saves significant propellant and system mass compared to a propulsive deceleration maneuver: a savings of 20-80%, depending on the mission. The In-Space Propulsion Technology Program has invested in Aerocapture technologies through the Entry Vehicle Technology project since 2002, advancing the Technology Readiness Level of the autonomous guidance software, the models used to predict the entry environments, thermal protection system materials and lightweight aeroshell structures, and sensors for measuring vehicle performance and improving future designs. With these achievements, Aerocapture is ready for space flight validation and first mission use.



Key Phases of the Aerocapture Maneuver

Space Environmental Effects Testing

There are several harsh space environments that could affect thermal protection systems and in turn pose risks to atmospheric entry vehicles. These environments include micrometeoroid impact, extreme cold temperatures, and ionizing radiation during deep space cruise followed by atmospheric entry heating. To characterize and mitigate these risks, candidate thermal protection materials were subjected to multiple tests including hyper velocity impact, cold soak, irradiation and arcjet testing at two NASA ARC facilities (AHF and IHF). The candidate materials included a wide variety of honeycomb based ablative materials as well as carbon based non-ablative thermal protection systems. The tests showed promising results for ablative thermal protection materials. The present study provides valuable information regarding the capability of various thermal protection materials to withstand harsh space environments that is critical to sample return, other planetary survey, as well as aerocapture-type missions.


Carbon-Carbon test sample, before, during, and after arc-jet testing.

High-Performance Rigid Aeroshell Development

A High-Performance 2.65m manufacturing development unit aeroshell has been fabricated in support of aerocapture and other missions with demanding EDL performance requirements. The aeroshell is undergoing Computed Tomography (CT) scanning at Lawrence Livermore National Labs (LLNL). The design of the 2.65m aeroshell includes a hot-structure capable of withstanding temperatures up to 400C, which is approximately 50% better than state-of-the-art designs. In addition, the 2.65m Aeroshell was fabricated using a modular assembly technique where individual panels are fabricated then assembled onto the primary structure. Gaps are filled with heat-shield material before the final surface is machined. This manufacturing method is critical for the design of large heat-shields that would be required to land large and heavy payloads on Mars or other planets, as well as for aerocapture missions. A world leader in CT scanning techniques, LLNL provides a tremendous value for NASA in this area. The CT scanning is intended to evaluate the bond between the heat-shield panels and primary structure, characterize the integrity of the panel gaps, and look for voids and density variations in the individual panels.


Key Phases of the Aerocapture Maneuver

Multi-mission technologies for Earth Entry Vehicles (MMEEV)

The Multi-Mission Earth Entry Vehicle (MMEEV) is a flexible design concept which can be optimized or tailored by any sample return mission, including lunar, asteroid, comet, and planetary (e.g. Mars), to meet that mission's specific requirements. Based on the Mars Sample Return (MSR) Earth Entry Vehicle (EEV) design, which due to planetary protection requirements, is designed to be the most reliable space vehicle ever flown, the MMEEV concept provides a logical foundation by which any sample return mission can build upon to meet their specific mission needs.

Key Phases of the Aerocapture Maneuver

To assess vehicle designs for multiple missions the Multi-Mission Systems Analysis for Planetary Entry (M-SAPE) tool is being developed and enhanced. The M-SAPE tool is an integrated multidisciplinary analysis system that is used to gain a better understanding of various entry system concept trades and their limitations. It improves the performance of the systems analysis team through automation of the EDL system engineering process and accelerates design activities such as trade studies, sensitivity analyses, Monte Carlo analyses, and vehicle optimization.

Testing in NASA Langley's Vertical Spin Tunnel was conducted to improve subsonic aerodynamic models of this class of vehicle. The objectives of the VST testing were to define usable subsonic center of mass limits to meet potential design requirements, and generate aerodynamic parameters for 6-degree-of-freedom simulations, for a range of MMEEV designs.